Radically Relational Tools: *A Design Framework to Explore Materials through Embodied Processes*

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In a context where fashion design and retail activities are increasingly transferring to the digital environment, mediating touch has become a matter of concern for the field. However, as literature shows, articulating our sensory experiences with materials is a challenging task. This position paper explores the experiential knowledge observed through embodied design processes. This is done by analysing our diverse approaches to introduce tools that help designers to understand people's perceptual experience with textile materials. We build on our previous research that identified relevant embodied processes to textile selection, and reflect on how we have explored how sensing technology can augment and empower each of these processes, thereby supporting design. We conclude by discussing the learning outcomes of analysing such tools, in order to reflect on the future of our research applied to the digital realm.

Keywords – Design, Embodied Interactions, Experiential Knowledge, Tacit Processes, Textiles.

Relevance to Design Practice – The paper presents a new design framework that positions relational principles and embodied processes in the core of the design practice as a radical proposal for the development of tools for textile explorations. Hence its title, Radically Relational. Relying on sensorial practices, it provides insights into tacit strategies which help to articulate non-verbal approaches to materials and to craft new forms of knowledge and modes of practice.

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Introduction

Articulating our tactile experiences with materials is a challenging task (Atkinson, Baurley, Petreca, Bianchi-Berthouze, & Watkins, 2016; Rognoli, 2010; Sonneveld & Schifferstein, 2008; Obrist, Seah, & Subramanian, 2013), and yet the tactile properties of products are crucial to support quality appraisal (Jordan, 2008). This is even more obvious with textiles, as the products that will be in close contact to the wearer's skin (McCabe & Nowlis, 2003). The communication of fabric feel is still little explored outside specialist research, and greatly relies on verbal descriptors, yet it is a rich experience that needs support and can be harnessed for improving products and services.

A "verbal language alone does not appear to be adequate for a comprehensive language of touch" (Teinaki, Montgomery, Spencer, & Cockton, 2012, p.170), as touch is a sense that can convey meaning (Spence & Gallace, 2011) and many people do not have the language to articulate these experiences verbally. Verbal accounts may be insufficient to describe our tactile experiences, as we perceive and experience the world with mind and body (Clark, 1999; Merleau-Ponty, 2010). The aesthetic experience emerges through interaction (Savva, Scarinzi, & Bianchi-Berthouze, 2012), thus, when touching physical textiles, we experience the presence of a thing; this is a multisensory encounter that elicits primary responses. The touch experience implies direct contact to enable appreciation; this suggests a bodily involvement, highlighting the importance of movement and proprioception in experiencing (Bianchi-Berthouze, 2013), here particularly with textiles. Our experience of fabrics is embodied and, in the case of fabric manipulations, it depends on our touch behaviour (sensorimotor involvement), the consequent textile deformation, and the multisensory feedback (tactile, auditory, and visual) afforded by this interaction (Atkinson et al., 2013).

Historically, humans have manipulated materials by hand, and the level of specialisation of hand sensitivity and skills has been studied from diverse perspectives, such as philosophy (Noë, 2004), phenomenology (Flusser, 2014), anthropology (Ingold, 2013), cognitive sciences (Kirsh, 2013), crafts (Lederman & Klatzky, 1987; Sennett, 2008), and, more recently, in human-computer interaction (Atkinson et al., 2013) and design (Petreca, Bianchi-Berthouze, & Baurley, 2015), just to mention a few. Tallis suggests that from tactile interaction we develop

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tactile knowledge, which is *a cumulative understanding of the properties of individual objects* (Tallis, 2003). This relies on our haptic skills, which are *understood as perception based on touch and grasp* (Smith, 2012), and on haptic perception, which is an *active touch perception* (Magnenat-Thalmann & Bonanni, 2008). Haptic skills link designers and consumers: Designers use touch to understand materials, materialise design intentions, and to imprint their signature on matter (Sennett, 2008), while touch is crucial for consumers when understanding, choosing or otherwise experiencing products.

Despite the importance of touch in understanding the objects and environments we interact with, as well as in communicating our experience to others, touch is still poorly present in online platforms, as these still rely mainly on visual and verbal communication. Online shopping for fashion has recently seen rapid expansion, but it is still facing the challenge of translating tactile experiences to an online environment (Perry, Blazquez, & Padilla, 2013). However, the incorporation of tactile elements in communicating products is seen to increase emotional responses in consumers that may influence their decision-making (Peck & Wiggins, 2006), reinforcing the imperative of touch for experiencing and understanding products through a meaningful encounter. Textile-based products are classified as a high-involvement product category that needs to be evaluated through multi-sensory channels (i.e., touch and visual, Workman, 2010). Indeed, touching fabrics is a multi-sensory, emotional, and cognitive experience, which is of importance to both experts (Petreca et al., 2015; Petreca, Bianchi-Berthouze, Baurley, & Tajadura-Jimenez, 2016) and non-experts (Atkinson et al., 2013; Atkinson et al., 2016; Cary, 2013) to appreciate and understand fabrics.

Further literature shows that tacit (Dormer, 2007) and embodied knowledge (Kirsh, 2013) are crucial to support an affective experience when interacting with digital representations of textiles (Petreca, Atkinson, Bianchi-Berthouze, Furniss, & Baurley, 2014). In a review of the literature (Petreca, Bianchi-Berthouze, Baurley, Watkins, & Atkinson, 2013) towards understanding which touch behaviour should be supported for an enhanced experience of digital textiles, we reported a set of prescribed gestures which are used by the textile industry to assess particular attributes rather than reflect the way people usually handle fabrics. As an example, the gesture "Fabric is taken between two fingers of both hands and it is pulled by one hand so that it would slide between two fingers." (Valatkiene & Strazdiene, 2006, p. 254), which is used to assess the surface of a textile, was not a gesture usually observed in natural interactions in-store (Atkinson et al., 2013). While this set of gestures already illustrates some of the needs that new technologies should support, they are too mechanised and tailored to the evaluation of the properties of the textile rather than to support the experience.

There are emerging opportunities to apply understanding of materials experience to new design spaces using current and emergent technologies. Research effort has been made to provide haptic feedback to represent the tactile properties of textiles (Dillon et al., 2000), with less attention given to the experience, and hence to the type of technology needed to convey the *textile hand*[1] in the digital environment [e.g., in tentative attempts to enable users to feel *virtual textiles* in online platforms through the use of integrated visual and haptic feedback (Magnenat-Thalmann & Bonanni, 2008)]. If there are no interfaces currently capable of fully supporting our tactile experience with textiles digitally, how can we experience digital textiles with or without specific haptic interfaces?

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Carmem Saito is a design practitioner and researcher working with a wide range of different media. With a background in Fashion Design, she has graduated from the MA Integrated Design at the Hochschüle für Künste Bremen. Additionally, she received a grant to work as a Design Researcher at the Royal College of Art in London, UK. Her interests are in questions of materiality emerging of the integration of digital technology in design processes and understanding material potentialities in touchable and untouchable forms.

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E-retail configurator platforms, such as Nike ID (a platform that enables personalisation of running shoes, by enabling the user to choose their preferred materials, colours, and embroidered inscriptions to a specific shoe design), are in need of presentation interfaces that provide information about the experience of materials, such as libraries of materials. The sense of touch can be complemented or be simulated by audio in order to give consumers multi-modal information to understand the properties of textiles. The fashion media website SHOWstudio (2006), for example, worked on a series of projects that explored the sound of clothes in which the aim was to investigate the audio options for representing the sound of clothes online.

When re-thinking the possibilities to improve the communication of the tactile properties of textiles digitally, one should consider not only the physical properties of the textiles, but also how these are experienced and enable understanding about materials and about how we feel them[2], and therefore enable the generation of knowledge that is embodied[3] (Petreca et al., 2013). New technologies should go beyond the physical deformation of the textile, and consider touch as an affective and embodied experience. In the next section, we present tools that were designed to explore embodied processes in experiencing textiles.

Background

Before the possibility of developing *alive, active and adaptive* materials emerged, textiles were already performing and relating in such a manner, as suggested by the iconic fashion designer Yohji Yamamoto *the fabric is alive and the real thrill lies in taming the tail of a living thing* (Salter, 2014). Textiles are soft materials that respond actively to being touched or otherwise moved, and are generally worn close to our bodies, adapting to it. In this paper, we use textiles as a case to explore the experiential knowledge generated through embodied design practices.

In this section, we present discrete tools that were recently developed to explore the sensorial experiences of textiles in design. The tools included here were designed for separate projects, as reported before (Atkinson et al., 2013; Petreca, 2016; Saito, 2015; Yu, 2016), and were never put together for a study. Each tool subsection contains a description of its motivation and of its design process. Although the projects are not part of the same research project we see related qualities in these tools that articulate similar research questions over the role of the body, touch, and material/digital interaction.

Detailed studies and results from the individual tools are not fully reported in this paper, as they were already reported in prior publications. The point in this paper is to reflect on how these tools can help to understand and investigate the textile experience, by experimenting with these embodied processes previously identified. We present the correlated analysis of the tools' design, and form a design framework of radically relational tools. This title acknowledges its emphasis on embodied experience, and its focus on tools that invite an exploration of the sensations and emotions that textile materials provoke, far beyond the visual or physical qualities. Additionally, the use of sensing tools is also disruptive, as these are used here as a means to bring focus to the subjective experience of materials whilst placing relationality at its centre, instead of the usual objective monitoring applications seen for such sensing devices.

The Pocket-Tool

The *pocket-tool* aimed to further understanding of this rich experience by investigating touch behaviour. The tool was developed with the context of a textile trade fair in mind, as this is an intense moment of textile selection, where the number of textiles on display is overwhelming. To make matters worse, designers cannot take home samples from a fair, and have to wait until suppliers send them later. In this scenario, what do designers need to remember about the textiles feeling when they return to their studios to share with their teams or to select a textile to order?

The pocket-tool was designed to investigate further the touch behaviour when handling textiles (Petreca et al., 2016). This tool aimed to draw attention to embodied sensorial experiences and to encourage the designers to verbally articulate their tactile experience.

The Pocket-Tool Design

The pocket-tool (Figure 1) is built with Arduino-based technology. It comprises a set of six force sensitive resistors (1.75 × 1.5" sensing area), and correspondingly six different textiles (all white or cream to reduce variables and avoid colour effects on the experience) shaped in the form of a small pocket within which the resistors can be inserted. As participants interact with the pockets a visualization of lines being plotted (one corresponding to each textile pocket) appears on a display (visible to participants), which reveal the amount of pressure applied and captured by the resistors as they touch.

In studies using this tool, participants were asked to find the fabric pocket that best represented four different properties, which were defined by a verbal descriptor, and were separately suggested by the researchers. The verbal descriptors used were: smooth, rough, soft, and hard.

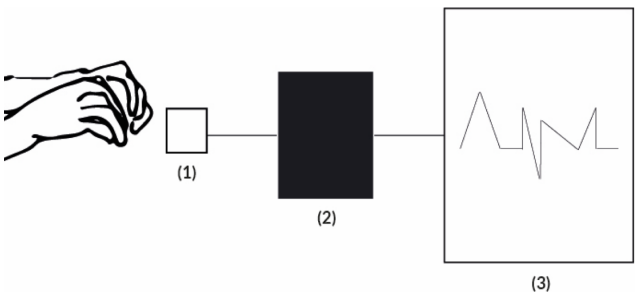


Figure 1. Schematics of the pocket-tool interaction, where (1) is a force sensitive resistor (*pressure sensor*), with 1.75 × 1.5" sensing area and is covered by a fabric pocket, (2) is the box holding the Arduino board and (3) represents the lines plotted as a result of the interaction.

The Haptic Sleeve

In efforts to understand how textile touch might be mediated, previous research (Cary, 2013) tried to identify the gestural language that reflects the experience of textile touch. The *haptic sleeve* is a proposition for mediated social touch, which was designed to explore how haptic feedback affected and/or altered the way people perceive textiles in mediated communication. The main objective of the haptic sleeve experiment was to see if people are able to tell from the way someone else is manipulating a fabric how the fabric feels.

Cary (2013) identified six commonly used textile handling gestures. In further study Cary (2013) verified that gesture does communicate the perception of a property of the fabric (e.g., communicates softness) viewed digitally. Cary's study showed that smooth ratings for the slow stroking gesture are always statistically higher than the smooth ratings for any other gesture. Hence, the slow stroking (caress) gesture did increase the ratings of a smooth fabric property. Hard ratings for the pressing gesture are always statistically higher than the hard ratings for any other gesture, except for rubbing. Therefore, these touch gestures could be used for further studying how to enhance the presence of tactile experience. In addition, warmth was also involved in this study as it is an important factor which is likely to be related to how people perceived softness and thickness of fabrics.

Outside the textile realm, research showed that the haptic channel enhanced or enriched mediated communication and provided the capability to exchange contextual and nonverbal cues (Chang, O'Modhrain, Jacob, Gunther, & Ishii, 2002; Rovers & van Essen, 2004, 2005). Studies investigating similarities between real and mediated social touch (Hertenstein, Holmes, McCullough, & Keltner, 2009) have used vibrotactile stimulation successfully, which indicate that this is suitable for touch-based activities (Huisman & Darriba Frederiks, 2013). Moreover, the forearm seems an appropriate body part for conducting mediated social touch (Hertenstein et al., 2009). Understanding the experience of handling fabrics as a touch-based activity, it is a promising approach for exploring haptic feedback and understanding vibrotactile stimulation patterns—or haptic patterns—to help people perceive textiles in mediated communication.

Tactile feedback generated by vibration motors were considered an appropriate means for simulating a touch gesture for perceiving textiles. By stimulating the vibration motors in sequence, it is possible to create recognizable precepts of continuous tactile movement (Kirman, 1974). When two vibrations points are placed on the body in close proximity a phantom vibration can be perceived. As such, it is possible to create the illusion of coherent continuously moving points of stimulation by controlling the timing intervals between two vibrations (Israr & Poupyrev, 2011). There are four key parameters, intensity of vibration, vibration duration of each motor, overlap of vibration duration between subsequent motors, and the distance between two subsequent motors. In order to address the research needs, two different types of haptic feedback were designed for rendering stroking and rubbing touch gestures.

The Haptic Sleeve Design

This haptic device consists of two modules: an automatic module and an interactive module. The automatic module includes a haptic layer and a heating pad layer that provides haptic feedback and warmth respectively through computer control. The interactive module is the one that users can play with to explore more haptic patterns by themselves. The haptic sleeve is made of viscose fabric and consists of two layers, one layer is a grid of eccentric rotating mass (ERM) vibrotactile motors which are attached to the inner surface of the haptic sleeve using velcro (Figure 2). Every vibration motor was wrapped by kinesiology elastic tape and sewn to velcro strips, which were in turn attached to the sleeve (Figure 2). The other layer consists of one DC-powered electric heating pad and one temperature sensor (DS18B20), which can work as a temperature-controlled heating pad to provide users with feelings of warmth. An Arduino UNO drives the ERM motors, heating pad, and temperature sensor. For the feeling of warmth, a heating pad and a temperature sensor were used to provide a controlled temperature of 42°C for people to receive the sensation of warmth (Ciesielska-Wrobel & Van Langenhove, 2012).

To allow for interaction, a regulator that consists of three potentiometers was used to adjust the value of three key parameters of ERM motors: intensity of vibration, vibration duration, and

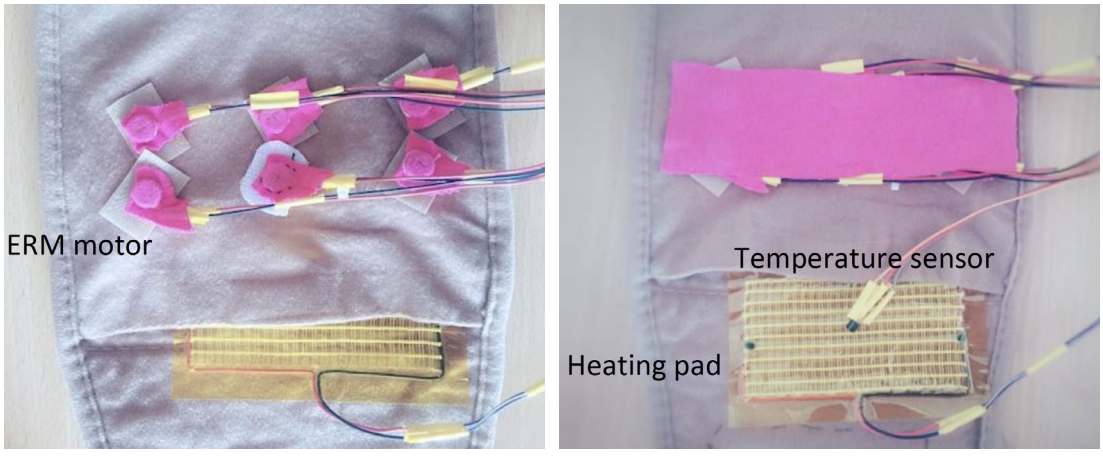


Figure 2. The *haptic sleeve* (including ERM motors, a heating pad and a temperature sensor).

overlap of vibration duration between subsequent motors (Figure 3a). Through manipulating three adjustable dials, participants can understand how different parameters could contribute to haptic feedback and the perception of fabrics (Figure 3b).

In terms of touch behaviour patterns, people's perception depends upon the frequency, amplitude, vibration and duration of each motor, overlap of vibration duration between subsequent motors, and the distance between two subsequent motors (Oakley, Kim, Lee, & Ryu, 2006). Through controlling these five parameters, diverse haptic feedback can be formulated to render different feelings for users.

This prototype enables people to better understand and design for these body experiences. It delivers haptic feedback that simulates touch gestures generally used to touch textiles that were smooth, rough, soft or hard. This included haptic feedback simulating gentle caressing and rubbing. Participants wear the haptic sleeve that outputs various feedback types synchronised with the video clips showing someone interacting with a fabric (Figure 4).

The Hyper Textile

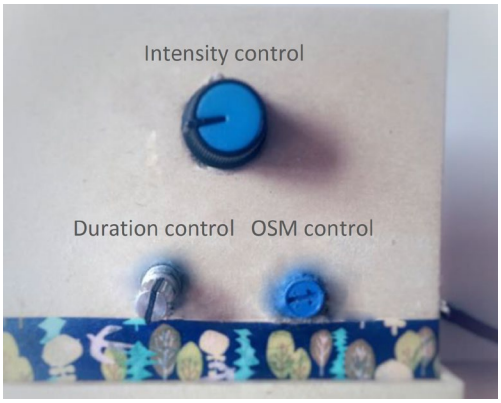
The *hyper textile* is a participatory artistic installation that invited participants to explore experimentally the reciprocal relationships between body and material, aiming to challenge our understanding of where the material begins and the immaterial ends. It was conceived as an interactive piece that proposes to empower design practices that are relational and augmented. It was exhibited in a gallery, and is the only tool described in this paper that was not the result of co-design, used for research purposes, or had potential commercial goals.

The context of the research behind the hyper textile is the advent of computational design and rapid prototyping in wearable technology in which the body becomes a new support for innovation. Fashion is a discipline that due to its proximity—and intimacy—to the body, can create knowledge to bridge object (dress) and subject (body), material (cloth) and immaterial (discourse). The hyper textile seeks to contribute to the current debate about the usage of digital technologies to mediate the design process (Petreca et al., 2013) by exploring new possibilities to rethink the role of the fashion practitioner and embodied modes of practice.

The Hyper Textile Design

Building on previous research on the role of tactility in the design process that revealed how complex touch behaviours are at both cognitive and subjective levels (Petreca et al., 2015), the hyper textile proposes to empower design practices that are relational and digitally augmented (Jurgenson, 2012), exploring the entanglements of material (matter) and immaterial (meaning) (Barad, 2012).

The hyper textile was composed of three different fabrics cut into strips two meters long (Figure 5), piezo sensors, audio cables, jumper wires, speakers, and an Arduino board. The fabrics were connected to sensors that captured movements when people touched the surface of the fabric amplifying the sound of each textile in real time (Figure 6). Each fabric also played additional audio files, which were generated using an Arduino board and controlled by a *pure data* command. There were three different audio files, which contained specific speech excerpts, each related to one of the three subdivisions of the research.



(a)


(b)

Figure 3. Devices for interaction with *haptic sleeve*: (a) 3 potential meters for interaction with *haptic sleeve*. (b) *haptic sleeve*.

Figure 4. Sequence of images of participant interacting with the *haptic sleeve*.

The audio files were randomized so that each spectator had a unique and unpredictable experience. Here, the invitation was to stage engagement between body and the material by allowing participants to sample sound fragments through manipulating the fabrics. The design process was an attempt towards weaving design statements and practices together. Fabric selection, cutting and sewing weren't parallel practices to sound recording, code writing and cable arrangements. The technological aspect gave support and enhancement to the other craft aspects of the installation. In the same way, the fabric properties—its touch, sound and feel—were equally essential to the technological functionality of the hyper textile. The final selection could be described as a mapping of material experiences rather than a selection of different textures, constructions and physical properties.

The first step was to prototype the installation. Piezo sensors were chosen, as they worked well both with the Arduino to play recorded sound through vibration data and as analogue contact microphones. Piezo sensors are also very thin and could easily be perforated and hand-sewn to fabrics. Once an initial version of the augmenting tool was built, it could be used to test different fabrics and frame fabric selection. Other tools such as recorders, wires and sensors helped inform the fabric selection in both aesthetic and technical aspects. The final three chosen fabrics were linen, silk, and a coated polyester, although there was no initial intent of choosing different fibre materials. Objectively, it was only important that the textiles had a different feel in terms of weight, temperature, texture, and sound.

The mechanical and digital materials are not there to simply add an immaterial layer or meaning to the material objects, but attempting to weave and augment both materials themselves, beyond the dualism of subject—digital media—and object—textiles. From this perspective, there was no hierarchical order of selection or development strategy between physical and digital materials.

When assembling all the parts together, it was important that the point of contact would be only the textile, so all sensors and cables were placed on the top, back and around the fabric to keep them far from participants' reach. This was not done to hide the electronic components as in a way of black-boxing the installation (Latour, 1999); it was still possible to see all electronic components and the computer running the code. This work plays with common dualistic assumptions of materiality, such as, the understanding of material as the idea of experiencing reality and immaterial as the virtual, subjective and affective experiences. Being able to physically touch a piece of fabric is a very concrete example of a *real* experience of interacting with physical material, but digital interactions are often considered not real. As this work tries to challenge these understandings and blur those boundaries, it was important that the trigger of the sound would not be a digital component but only the fabric touch, in order to create a seamless interaction through a familiar element.

The iShoogle

The *iShoogle* is an interactive digital textile swatch that allows for synchronised movement and visual feedback, according to the interaction with the video displayed on a touchscreen device (Atkinson, Watkins, Padilla, Chantler, & Baurley, 2011; Atkinson et al., 2013; Orzechowski, 2016).

The iShoogle Design

Research on digital (or virtual) textiles has focussed on haptic feedback to convey its hand qualities, however the touch behaviour used to interrogate textiles has been largely overlooked. This gap in research was investigated through the creation of iShoogle interactive digital textile swatches. In this case, when communicating about textiles digitally. Using a design research approach (reported in Atkinson et al., 2013) the gestures used by non-experts to assess textiles through hand tactile interaction were explored, and from the observations, techniques to create an interactive simulation of digital textile handling for a touch-based display were devised. The gestures people most commonly use to discern the hand of textiles were investigated in laboratory and in-store studies. Triad-sorting studies (Bang, 2009) were conducted to better understand how people perceive textiles by revealing the terms people use to describe their hand. As reported by Atkinson et al. (2016), this was done using a delimited set of cotton fabrics commonly used in clothing which were compared by grouping the two most similar and naming how they differ from the other.

A further study was then conducted in a London branch of a mass-market fashion retailer, to observe the particular gestures used by consumers when evaluating clothing. From these studies

Figure 5. Hyper textile installation.

Figure 6. Hyper textile installation in use.

emerged the understanding of how people inherently touch and handle textiles, which generated a taxonomy of gestures (the five most common gestures are included in Table 1) that could be further explored for the development of interactive videos (Atkinson et al., 2013).

Table 1. Five most observed textile evaluation gestures in retail as reported by Atkinson et al. (2013)**.**

1	Thumb and forefinger edge rub
2	Thumb and forefinger edge stroke
3	Hand inside pat
4	Grab edge and scrunch
5	Multi fingertip stroke

Besides considering people's perceptions and modes of interaction with textiles, the translation of the tactile properties of the textiles demanded a greater understanding of the intrinsic characteristics of these textiles. Explorations of properties of textiles were conducted with initial probes to investigate means to convey their tactile qualities digitally through videos. These encompassed fabric treatments and objective measurements, sound recording and lighting techniques. The results for these explorations (Atkinson et al., 2011; Atkinson et al., 2013) informed the filming of the fabrics, and supported the identification of the best conditions to create digital textiles, such as fabric presentation, lighting, and methods of manipulation.

Building on the understanding gathered through the empirical studies was crucial to creating digital samples of textiles. The methods to produce interactive content for the application iShoogle—that would reflect the observed fabric manipulations included: designing filming (Figure 7 shows the rig that was created to support various backing plates and media on which textiles were placed and manipulated) and lighting methods to bring the textile tactile properties alive in touchscreen interactive media (Atkinson et al., 2013).

Figure 7. Research team working on the fabric filming using the rig designed for *Digital Sensoria* project.

The videos produced from real (physical) textiles were transformed into interactive videos using the ShoogleIt.com website (Padilla & Chantler, 2011), so that they could be made available in the iShoogle interface for iPad (Orzechowski, 2016). The resulting interactive videos on the application enable people to manipulate digital textiles through different gestures (e.g., scrunch gestural interaction in Figure 8) and are meant to convey behaviour of fabrics (e.g., movement qualities). The selected gestures used in the iShoogle interface emerged from observations in the retail and laboratory studies previously mentioned, and were matched to the native iOS gestures, resulting in three interaction types: stroke (one finger moving across the screen), pinch (two fingers moving together and apart), and scrunch (three or more fingers converging on a central point). The evaluation experiments reported by Atkinson et al. (2013) showed that the gestural interaction impacts on the level of engagement of the user, possibly due to both visual and kinaesthetic feedback.

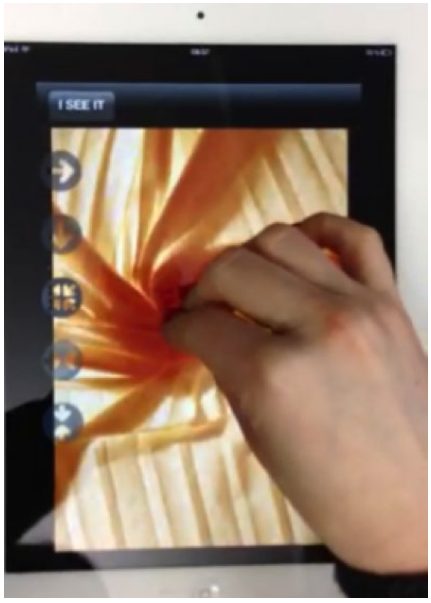


Figure 8. Digital textile response to the interaction type *scrunch.*

Analysing the Embodied Processes of the Tools

We use a model of textile experience (Petreca et al., 2015) as a platform to analyse the set of four sensing tools presented in the background section. This model revealed three main touch behaviour types (*active hand*, *passive body*, and *active tool-hand*) and three tactile-based phases, as follows:

- *Situate* describes the first experience with the material, it is the initial experience where designers, through a combination of touch behaviours, using mostly hands and sometimes other parts of the body, in a first attempt to grasp a material's properties. The main touch behaviour observed here is active hand.
- *Simulate* is when designers once comprehending the material, start to play with the fabric in a creative manner. They put the material through a series of tests to explore different

concepts. The body, or parts of it, is/are used as a platform for such simulations. The main touch behaviour observed here is active tool-hand and passive body.

- *Stimulate* characterizes the phase in which the designer goes beyond the physical properties of the material and initial concepts. At this moment, the designer starts to envision complete new possibilities for the material. This phase involves the use of the entire body and the creation of metaphors to externalize more poetical and powerful material becomings, as well as subjectivities. The three touch behaviour types are observed here.

We use this model to analyse the four discrete tools presented in the background section, to show how sensing technology could augment and empower these embodied processes.

In this section, firstly we analyse the types of outputs that each specific tool enables, and how it stands in relation to the diverse types of textile experiences proposed by (Petreca et al., 2015). Secondly, a correlated analysis of the tools' design is presented, and is formalised into a *design framework of radically relational tools*.

The Pocket-Tool Contribution: Discovering What the Body Does

As reported previously (Petreca, 2016; Petreca et al., 2016), the use of the pocket-tool was revealing because it allowed a disruption in the way designers normally interact with textiles and helped in facilitating conversations around this experience, as it enabled the articulation of aspects that generally remain unspoken or unconscious. The pocket-tool contributed to our understanding that *textile touch is a multisensory experience,* going beyond the tactile appreciation with hand manipulation only, and that this is a *very complex experience to communicate*. Also, it revealed the *importance of tacit knowledge in experiencing a textile during selection*, particularly as designers showed interest in the possibility of more focused textile manipulation and on the emergent reflections through the process, also enriched by visual feedback, which were all stimulated by the tool. They regarded this as a means to support their explorations and consequently their understanding of a textile, after reflecting on their lack of awareness about their interactions with textiles. This was highlighted by an interest in seeing hands and seeing the lines plotted from the Pocket-Tool; and this includes information both about themselves or other people touching. A full account on these studies results is available in (Petreca, 2016; Petreca et al., 2016).

With the pocket-tool designers revealed a focus on their bodily experience, which led to reflection and understanding of what they were doing. The mechanism of the pocket-tool was based on the sensor measuring the interaction and providing a focused attention on the part of the body that is measured, as well as the feedback provided, which facilitates the understanding of the body part that is engaged. Hence, the pocket-tool provided at the same time a top down and a bottom up process; top down because the person sees the graph and realises what the body is doing, and bottom up because as one focus on a body part being measured, there is reflection on what the body is doing, discovering what the body movement leads to in terms of emergent understanding from the interaction—about the fabric and about oneself.

This is related to the *Situate* tactile-based phase, which is about the understanding one gets from the fabric and from oneself, and is emergent from the interaction between both. The pocket-tool contributes to enhancing people's internal feedbacks, i.e., the proprioceptive feedback that are very subtle, as if it was creating, or rather enabling an additional sense of the experience, which comes from this focused attention. Finally, there are many possibilities in which this type of interaction could be further explored in future developments to expand the pocket-tool, since in terms of how the body is moving, one could work gradually to explore how the body is experiencing from the local part, extending to the full-body.

The Haptic Sleeve Contribution: Exploring Different Properties of Textiles and Experiences Remotely

As reported in a previous study (Yu, 2016) the majority of participants felt more connected to the textiles when experiencing them via the haptic sleeve. When participants were asked to interact with the haptic sleeve through three regulators and explore more haptic feedback (Figure 4), it was noted that this approach can help them to better understand not only how the haptic feedback can contribute to the experience, but also how the textile and touching experience are related.

The interactions provided by the haptic sleeve allow enhancing the *Simulate* and *Situate* phases of the experience. The *Simulate* comes from the fact that one can change and try other parameters, which enables the exploration of different properties of textiles and experiences. The *Situate* is rather a *co-Situate,* as the haptic sleeve allows one to situate with someone else, as users try to share subjective experiences about the feeling of a textile. When interacting with the haptic sleeve, users change the parameters, or somebody else is moving the potentiometer, that is, *Simulate* on one user what someone else is feeling.

Here there is partially *Situate* and partially *Simulate*, as people could touch and feel what is happening on the other, or receive a caress adjusted by someone else, and we want to see how the body feels that. People explore it, and use different parameters. By changing the parameters, they were playing with different perceptions, through the different touch they would receive. It is interesting to see how other people *Situate*, so it could be a device for communication between designer and consumer.

The Hyper Textile Contribution: Discover How You and the Textile Work Together

This device enables an augmented exploratory experience through the relationship that both amplifies the senses and blurs the boundaries between the textile and its digitally augmented properties (material) in relation to its affective and emotional experience (immaterial). This augmented interaction creates a scenario for a more thorough and expansive material experience, which allow for possibilities that cross and go beyond its material properties.

The hyper textile is an enhanced representation of the interaction between a person and a textile sample. In this scenario, not only the sample considerably larger, which encourages full-body interaction, but there is also an additional augmented sense, which is in this case the sound—something that is always present in textile handling, but that is not so easily perceived or attended to. With that, it enhances and augments *Stimulation*, which is facilitated by creating an extra channel of communication with textiles — not touch, or visual, but in this case sound, which makes the interaction much more vivid and inviting. Consequently, people approach and remain for a long while exploring the textile. In observing the participants, we can notice them interacting more because the textile in movement *talks* to them; their interaction is sonified.

Given the nature and context of this piece, there were no formal outcomes or records of participants' experiences. However, it was observed that participants would start by interacting with their hands and progressively involve their whole bodies into the experience as it increases the awareness of their interaction through sound, movement and silence. It was clear that the work evoked modes of active touch, and a heightened awareness of people's experiences through a digital method and yet, although it was presented as an interface for material exploration, it was not generally perceived as a machine. Therefore, the hyper textile elicits multi-sensorial experiences by augmenting one aspect of the textile and we see potential in further exploring this device as a tool and mode of research.

Here we select what to represent about the fabric, and about the body. This creates an engaging interaction with the fabric, and by inviting interaction it may lead to experiences that resemble the *Stimulate* tactile-based phase. In this case the sound was used, demonstrating how the *Stimulate* phase can be enhanced through interaction between the body and textiles. In future this effect could be explored using other sensory channels. Also, *Stimulation* can be empowered by the fact that the more one engages with the material, the more they can discover about it.

The iShoogle Contribution: Discover a Multi-Sensory Experience of the Textile (and What is Missing from It)

This initial attempt to create digital textile tools that mimic textile manipulation on a touchscreen device is still considered to provide an impoverished experience by fashion and textiles professionals, but is a step forward from still photographs (Petreca et al., 2014) which are currently used during the *Situate* phase to gain an initial understanding of a fabric via digital media. This work adds the importance of touch behaviour in the experience of digital textiles, adds movement through moving images, and includes the user experience by producing content that is familiar. However, the results of the user studies show that the flat touchscreen seems to limit and alter the types of interaction people would expect from a digital textile, compared to their most commonly used touch behaviour when engaging with a real textile (Atkinson et al., 2013). Also, designers report that such limitation in interaction enables them to only get a sense of the textile movement, but that they still need physical samples to feel (Petreca et al., 2014). This demonstrates that through an attempt to replicate an embodied experience using as many sensory modalities as possible, the divergence from the true experience can focus attention on the aspects which are perceived to be missing or inaccurate, facilitating greater reflection on the tacit aspects of the experience.

When interacting with the iShoogle fabric swatches the focus is on the movement in the finger and hands along with the resultant deformation of the fabric swatch. Thus, the iShoogle fabric swatches represented visual, aural, and kinaesthetic sensation, offering a richer sensory experience which exposed the contrasting lack of the tactile sensation in this tool and led to reflection on this unrepresented sense. This has the potential to enrich the *Situate* phase of experiencing a textile when the real, physical fabric is not available.

A Design Framework for Radically Relational Tools

Throughout this paper we have presented diverse tools and methods to investigate sensorial experience (Atkinson et al., 2013; Atkinson et al., 2016; Petreca et al., 2016; Saito, 2015; Yu, 2016) and select textiles (Petreca et al., 2015; Petreca, 2016). Although each tool explored different aspects of the perceptual experience of textiles in diverse contexts and with different audiences, in this process we have realised the potential of developing a framework to engage with textile materials, in order to aid designers in focus, elaboration, articulation, and communication of the haptic experiences they have through and with textiles. And this conversion of sensorial investigational methodologies is what we call a radically relational framework or radically relational tools.

The tools explore converging themes and show a pattern of touch behaviour explorations in relation to the 3 tactile-based phases of the textile experience: *Situate*, *Simulate*, and *Stimulate*. Figure 9 shows that the tools explore diverse manners of (1) mediating fabric manipulation and (2) generating feedback accordingly to manipulation of fabrics. Here, they are presented not as final solutions, but experiments that showcase a proof-of-concept, namely that tools can be brought in to support the design process through enhancing and empowering embodied processes.

Figure 9 illustrates the manner in which these tools may support the design decisions of what to represent about the fabric and about the body, and how these are tailored according to the level of focus that is desired to work at: the finger, or the arm, or the whole body. These have happened mainly through two types of design strategies:

1. Focusing:
    a. on the body part,
    b. on the textile interaction (which may change—shift the focus by stressing one part or another), and/or
    c. on who is generating (oneself, or somebody else).
2. Digital Feedback: the projects included herein have mostly prioritised one sensory modality to be represented, specifically visual, tactile, auditory, or kinaesthetic.

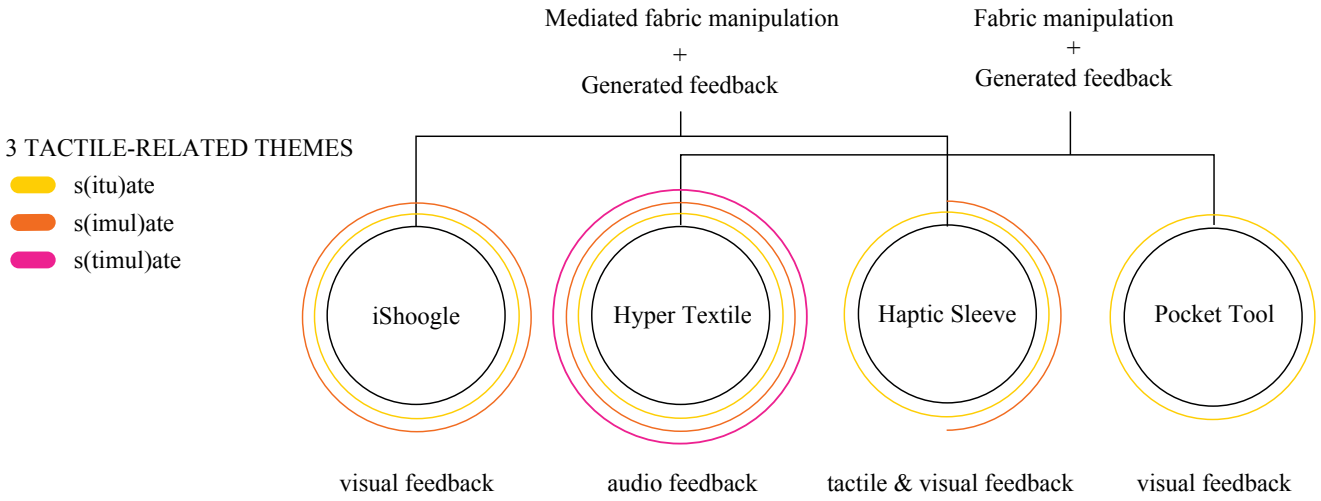


Figure 9. Radically Relational design tools.

Adding to these, the tools presented in this paper demonstrated four main routes to focus on the embodied process, which enable such Radically Relational experiences:

- *Immersion in experience*—by developing and delivering the means (tool or method) for designers to have an immersion in their own touch experience of a textile. The effect noticed was that when designers have the agency to navigate their experience, they will focus their attention on aspects that emerge as relevant during its course;
- *Mediating the experience*—in the current context touch experiences with textiles are sometimes lacking, for example in digital design or online shopping, and by receiving a mediated touch (in this case through a haptic sleeve), participants feel more connected to the textiles and their experience is enhanced;
- *Augmenting the experience*—by purposely focusing on certain qualities of an experience that are heightened to provoke and evoke reactions, and the effects observed are of a more playful interaction, that keeps the designers actively exploring and engaged in the experience of involving the whole body in such explorations.
- *Replicating the experience*—by digitally re-creating an embodied experience as fully as possible with current technologies (in this case with multi-modal iShoogle textile swatches) the attention of participants is focussed on the missing elements of the embodied experience. This invites consideration of previously tacit elements of the experience, which are highlighted by their absence or incongruity.

These four approaches—immerse, mediate, augment, and replicate—show possible paths to further our understanding of the embodied experience with textiles, through investigations into touch interactions. As our processes and products will increasingly inhabit blended spaces, between physical and digital, if we are willing to create more alive, active, and adaptive materials, we believe further exploring the routes we have proposed through this paper will have a disruptive impact on the design field—of designing with our materials, with our whole bodies, and contexts engaged. Table 2 synthesises how each tool explored Focusing, the types of Digital Feedback, and the Relational Experience.

As can be seen from Table 2, by testing how technology can empower embodied processes we have completed the initial proposed framework, based on the 3 tactile-based phases (Situate, Simulate, and Stimulate). Reflecting back at these proposed tools, we realise that these strategies also led to particular ways in which we have structured our approach, and which could be taken forward as themes to be further explored for the development of other new tools.

Table 2. Diverse tools to support embodied design processes.

Strategies		Pocket-tool	Haptic sleeve	Hyper textile	iShoogle
Focus	Body Part	Hand	Arm	Full-body	Hand
	Textile Interaction	Textile with minimum interference (sensor); Active interaction	No direct interaction with the textile; Passive reception of haptic patterns	Direct and active interaction with the textile	Active, digital interaction with the textile on screen
	Who Is Generating	Oneself	Oneself or somebody else	Oneself	Oneself
Digital Feedback		Visual	Tactile	Auditory	Visual and kinaesthetic
Relational Experience		Immersion in experience	Mediating the experience	Augmenting the experience	Replicating the experience

Overall, these tools show diverse approaches to support investigations on how designers relate with materials, particularly textiles, and use their sensorial body to experience them. With this, we complete the framework that was introduced with the 3 tactile-based phases of the textile experience, by saying how technology can empower that exploration. Finally, we discuss the learning outcomes from designing such tools, in order to reflect on the future of our research.

Discussion

When rethinking the possibilities of improving the communication of the tactile properties of textiles digitally, one should consider not only the physical properties of the textiles, but also how these are experienced and enable understanding about materials and about how we feel them, and therefore enable the generation of knowledge that is embodied (Petreca et al., 2013). New technologies should go beyond the physical deformation of the textile, and consider touch as an affective and embodied experience. This is what our "Radically Relational" tools endeavour to do.

We call these tools radical in the sense that relational, or embodied design practices can challenge the structures of western rationalism and Cartesian tradition embedded in design practices, industry and scholarship (Escobar, 2018), as well as the hierarchy of technical knowledge over tacit knowledge (Petreca et al., 2017). Relational refers to the embodied focus of this work. We want to propose methodologies that allow designers to wholly embrace an embodied, dynamic, affective, subjective, relational practice with the material and their subject matter. Similar to the Brazilian artist Lygia Clark's *Objetos Relacionais* (Relational Objects), the materials used in the presented tools invite an exploration of the sensations and emotions these materials provoke as opposed to the visual or physical qualities. This relational approach, for Clark, is a tool for structuring the self in relation to otherness. In the context of this paper and the works presented here, a relational approach is also key to disrupt ideas of hierarchical epistemologies of knowledge (De Sousa Santos, 2007). Furthermore, the digital mediation present in the works shown in this paper helps to bring focus to the material experience and puts relationality at its centre.

Building on the framework described above, we can open up the discussion to propose some following concrete applications that may benefit from the findings of the four projects presented:

1. Design Education and Practice: There is an underexplored potency in this approach, that is to promote an *ecology of knowledge* (De Sousa Santos, 2007) in design research and practice. This would lead to recognition of an epistemological diversity of knowledge and its actors within design. One example, in particular to the theme of this paper, is the validation of tacit knowledge as opposed to hard sciences only. Within this mindset, there is an opportunity to develop tools to support designers or design teams—for individual exploration or shared (remote communication) exploration. Such tools could facilitate processes of articulation and communication on a tacit basis, i.e., relying on the designer's subjective experience and experiential knowledge.
2. Co-Design: The devices described in this paper deal with both personal and shared material experiences, as well as the use of data representation and collection as non-verbal communication tools. Such affordances can support co-creation practices, as they might benefit from new possibilities for communicating material explorations between multiple stakeholders.
3. Commercial/Industrial Settings: Radically relational approaches to design offer opportunities to explore commercial contexts within online and offline environments (local or remote). It is safe to affirm that when both environments are explored in a hybrid manner, this can lead to more seamless user experiences. We could easily see this working in consumer customisation settings, with services that combine in-store and/or online experiences. Furthermore, these methods of exploration and collection of information around textile's embodied experiences could form a basis for defining a *Textile ID*, which we envision as a database for textile descriptors that go beyond the rigid industry standards we have today.

Moreover, our research challenges current understandings of design practice, as these tools open up paths for investigations within a hybrid, interdisciplinary approach, combining physical and digital spaces. Finally, despite the emergence of tools that can directly capture how a person feels about textiles (Singh et al., 2014), we argue that technologically aided material engagement and exploration can lead to exciting new *radically relational* developments in the ways we think and do design. In future work, we hope to further stretch the use of technology to explore material interactions with the support of augmented reality, virtual reality and haptic technologies.

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Endnotes

1. Fabric hand is an industry term that refers to the feel of the fabric. The definition that we usually adopt defines textile hand as "the tactile sensations or impressions that occur when fabrics are touched, squeezed, rubbed or otherwise manipulated" (American Association of Textile Chemists and Colorists, 2012, p. 404).
2. Here reference is made to the proposition by Merleau-Ponty (2010, p. 95) on double sensations, which suggests the experience of touch, touching and being touched are simultaneous, that is, a person touching is actor and object of the perceptual experience.
3. Here the use of the term embodied is related to the corporeal basis of human experience (Dewey, 1980). In this sense, the way a body moves and experiences the world not only is a reference to human understanding and meaning-making [e.g., in language this is seen through embodied metaphors, as demonstrated by Lakoff and Johnson (1999)] as it has the potential to communicate feelings to observers (Gao, Bianchi-Berthouze, & Meng, 2012; Hertenstein et al., 2009) and to inform oneself about our own feelings (Petreca, Bianchi-Berthouze, Baurley, Watkins, & Atkinson, 2013). Hence, the embodied design processes are considered a crucial part of the experiential forms of textile interaction, as these are fundamentally related to creative processes. As proposed by Höök (2018) in Designing with the Body, design practice needs theories and methods to consider diverse levels of materials experience (Giaccardi & Karana, 2015) through the entire life of a product, i.e., in practices of design and use. Such embodied (design) processes have been proposed earlier though embodied interaction frameworks, of which Dourish (2001) is the most acknowledged. Embodied interactions theory and methods have inspired the work of many since, but this has never been applied to work with textiles, particularly in the blend of physical and digital experiences.

References

1. American Association of Textile Chemists and Colorists. (2012). *AATCC test method 202:2012: Relative hand value of textiles: Instrumental method* (pp.404-406). Research Triangle Park, NC: AATCC.
2. Atkinson, D., Watkins, P., Padilla, S., Chantler, M., & Baurley, S. (2011). Synthesising design methodologies for the transmission of tactile qualities in digital media. In *Proceedings of the Conference on Digital Engagement* (pp. 15-17). Piscataway, NJ: IEEE.
3. Atkinson, D., Orzechowski, P., Petreca, B., Bianchi-Berthouze, N., Watkins, P., Baurley, S., & Chantler, M. (2013). Tactile perceptions of digital textiles: A design research approach. In *Proceedings of the Conference on Human Factors in Computing Systems* (pp. 1669-1678). New York, NY: ACM.
4. Atkinson, D., Baurley, S., Petreca, B., Bianchi-Berthouze, N., & Watkins, P. (2016). The tactile triangle: A design research framework demonstrated through tactile comparisons of textile materials. *Journal of Design Research, 14*(2), 142-170.
5. Bang, A. L. (2009). Triad as a means for dialogue about emotional values in textile design. In *Proceedings of the 8th Design Conference of European Academy* (pp. 44-49). Aberdeen, Scotland: The Robert Gordon University.
6. Barad, K. (2012). On touching–The inhuman that therefore I am. *Differences, 23*(3), 206-223.
7. Bianchi-Berthouze, N., 2013, Understanding the role of body movement in player engagement. *Human Computer Interaction 28* (1), pp. 40-75.
8. Blessing, L. T. M., & Chakrabarti, A. (2009). *Drm, a design research methodology*. London, UK: Springer-Verlag.
9. Cary, L. (2013). *Exploring a language of gestures and emotional responses to textiles* (Unpublished master thesis). University College London, London, UK.
10. Chang, A., O'Modhrain, S., Jacob, R., Gunther, E., & Ishii, H. (2002). ComTouch: Design of a vibrotactile communication device. In *Proceedings of the 4th Conference on Designing Interactive Systems* (pp. 312-320). New York, NY: ACM.
11. Ciesielska-Wrobel, I. L., & Van Langenhove, L. (2012). The hand of textiles–Definitions, achievements, perspectives–A review. *Textile Research Journal, 82*(14), 1457-1468.
12. Clark, A. (1999). An embodied cognitive science? *Trends in Cognitive Sciences, 3*(9), 345-351.
13. De Silva, P. R., Kleinsmith, A., & Bianchi-Berthouze, N. (2005). Towards unsupervised detection of affective posture nuances. In *Proceedings of the International Conference on Affective Computing and Intelligent Interaction* (pp. 32-39). Berlin, Germany: Springer.
14. De Sousa Santos, B. (Ed.) (2007). *Another knowledge is possible. Beyond northern epistemologies.* London, UK: Verso.
15. Dewey, J. (1980). *Art as experience.* New York, NY: Penguin Group.
16. Dillon, P., Moody, W., Bartlett, R., Scully, P., Morgan, R., & James, C. (2000). Sensing the fabric: To simulate sensation through sensory evaluation and in response to standard acceptable properties of specific materials when viewed as a digital image. In *Proceedings of the International Workshop on Haptic Human-Computer Interaction* (pp. 205-218). Berlin, Germany: Springer.
17. Dormer, P. (2007). *The culture of craft: Status and future.* Manchester, UK: Manchester University.
18. Dourish, P. (2001). *Where the action is: The foundations of embodied interaction.* Cambridge, MA: MIT.

19. Escobar, A. (2018). *Designs for the pluriverse: Radical interdependence, autonomy, and the making of worlds.* Duke University Press.
20. Flusser, V. (2014). *Gestures.* Minneapolis, MN: University of Minnesota.
21. Gao, Y., Bianchi-Berthouze, N., & Meng, H. (2012). What does touch tell us about emotions in touchscreen-based gameplay? *ACM Transactions on Computer-Human Interaction, 19*(4), Art. 31.
22. Giaccardi, E. & Karana, E., 2015. Foundations of Materials Experience: An Approach for HCI. In: *Proceedings of the 33rd SIGCHI Conference on Human Factors in Computing Systems*, 18-23 April 2015, Seoul, Korea. New York: ACM, pp. 2447-2456.
23. Hertenstein, M. J., Holmes, R., McCullough, M., & Keltner, D. (2009). The communication of emotion via touch. *Emotion, 9*(4), 566-573.
24. Höök, K. (2018). *Designing with the body: Somaesthetic interaction design.* Cambridge, MA: MIT.
25. Huisman, G., & Darriba Frederiks, A. (2013). Towards tactile expressions of emotion through mediated touch. In *Proceedings of the Conference on Human Factors in Computing Systems* (Extended Abstracts, pp. 1575-580). New York, NY: ACM.
26. Ingold, T. (2013). *Making: Anthropology, archaeology, art and architecture.* London, UK: Routledge.
27. Israr, A., & Poupyrev, I. (2011). Tactile brush: Drawing on skin with a tactile grid display. In *Proceedings of the the Conference on Human Factors in Computing Systems* (pp. 2019-2028). New York, NY: ACM.
28. Jordan, P.W., 2008. The four pleasures: understanding users holistically. In: *2nd International Conference on Applied Human Factors and Ergonomics*. Las Vegas: USA Publishing. pp. 1-10.
29. Jurgenson, N. (2012). When atoms meet bits: Social media, the mobile web and augmented revolution. *Future Internet, 4*(1), 83-91.
30. Kirman, J. H. (1974). Tactile apparent movement: The effects of interstimulus onset interval and stimulus duration. *Perception & Psychophysics, 15*(1), 1-6. http://doi.org/10.3758/BF03205819
31. Kirsh, D. (2009). Knowledge, explicit vs. implicit. In T. Bayne, A. Cleeremans, & P. Wilken (Eds.), *The Oxford companion to consciousnes*s (pp. 397-402). Cambridge, UK: Oxford University.
32. Kirsh, D. (2013). Embodied cognition and the magical future of interaction design. *ACM Transactions on Computer-Human Interaction, 20*(1), 1-30.
33. Kleinsmith, A., De Silva, P., & Bianchi-Berthouze, N. (2005). Grounding affective dimensions into posture features. In *Proceedings of the International Conference on Affective Computing and Intelligent Interaction* (pp. 263-270). Berlin, Germany: Springer.
34. Lakoff, G., & Johnson, M. (1999). *Philosophy in the flesh: The embodied mind and its challenge to western thought.* New York, NY: Basic Books.
35. Latour, B. (1999). *Pandora's hope: Essays on the reality of science studies.* Cambridge, MA: Harvard University.
36. Lederman, S. J., & Klatzky, R. L. (1987). Hand movements: A window into haptic object recognition. *Cognitive Psychology, 19*(3), 342-368.
37. Loy, J., & Canning, S. (2016). Clash of cultures: Fashion, engineering, and 3D printing. In A. M. Connor & S. Marks (Eds.), *Creative technologies for multidisciplinary applications* (pp. 25-53). Hershey, PA: IGI Global.
38. Magnenat-Thalmann, N., & Bonanni, U. (2008). Haptic sensing of virtual textiles. *Human Haptic Perception: Basics and Applications,* 513-523.
39. McCabe, D. B., & Nowlis, S. M. (2003). The effect of examining actual products or product descriptions on consumer preference. *Journal of Consumer Psychology, 13*(4), 431-439.
40. Merleau-Ponty, M. (2010). *Phenomenology of perception.* London, UK: Routledge.
41. Noë, A. (2004). Action in perception. Cambridge, MA: MIT.
42. Oakley, I., Kim, Y., Lee, J., & Ryu, J. (2006). Determining the feasibility of forearm mounted vibrotactile displays. In *Proceedings of the 14th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems* (pp. 27-34). Piscataway, NJ: IEEE.
43. Obrist, M., Seah, S. A., & Subramanian, S. (2013). Talking about tactile experiences. In *Proceedings of the Conference on Human Factors in Computing Systems* (pp. 1659-1668). New York, NY: ACM.
44. Orzechowski, P. M. (2016). *Pinching sweaters on your phone – iShoogle: Multi-gesture touchscreen fabric simulator using natural on-fabric gestures to communicate textile qualities.* (Doctoral dissertation). Heriot-Watt University, Edinburgh, Scotland.
45. Padilla, S., & Chantler. M. (2011). ShoogleIT.com: Engaging online with interactive objects. In *Proceedings of the Conference on Digital Engagement* (pp. xx-yy). Newcastle, UK: Newcastle University.
46. Peck, J., & Wiggins, J. (2006). It just feels good: Customers' affective response to touch and its influence on persuasion. *Journal of Marketing, 70* (4), 56-69.
47. Perry, P., Blazquez, M., & Padilla, S. (2013). Translating the need for touch to online fashion shopping via digital technology. In *Proceedings of the 1st International Conference on Digital Technologies for the Textile Industries* (pp. 5-6). Manchester, UK: The University of Manchester.
48. Petreca, B., Bianchi-Berthouze, N., Baurley, S., Watkins, P. A., & Atkinson, D. (2013). An embodiment perspective of affective touch behaviour in experiencing digital textiles. In *Proceedings of the Humaine Association Conference on Affective Computing and Intelligent Interaction* (pp. 770-775). New York, NY: ACM.

49. Petreca, B., Atkinson, D., Bianchi-Berthouze, N., Furniss, D., & Baurley, S. (2014). The future of textiles sourcing: Exploring the potential for digital tools. In J. Salamanca, P. Desmet, A. Burbano, G. Ludden, & J. Maya, (Eds.), In *Proceedings of the 9th International Conference on Design & Emotion* (pp. 366-377). Bogotá, CO: Ediciones Uniandes.
50. Petreca, B., Bianchi-Berthouze, N., & Baurley, S. (2015). How do designers feel textiles? In *Proceedings of the International Conference on Affective Computing and Intelligent Interaction* (pp. 982-987). Piscataway, NJ: IEEE.
51. Petreca, B., Bianchi-Berthouze, N., Baurley, S., & Tajadura-Jimenez, A. (2016). Investigating nuanced sensory experiences in textiles selection. In *Proceedings of the International Joint Conference on Pervasive and Ubiquitous Computing* (Adjunct, pp. 989-994). New York, NY: ACM.
52. Petreca, B. (2016). *An understanding of embodied textile selection processes & a toolkit to support them* (Doctoral dissertation). Royal College of Art, London, UK.
53. Petreca, B., Saito, C., Yu, X., Bianchini-Berthouse, N., Brown, A., Cox, J., …Baurley, S. (2017). Radically relational: Using textiles as a platform to develop methods for embodied design processes. In *Proceedings of International Conference on Experiential Knowledge and Emerging Materials* (pp. 261-274). Delft, the Netherlands: Delft University of Technology.
54. Polanyi, M. (1967). *The tacit dimension.* New York, NY: Anchor Books.
55. Rognoli, V. (2010). A broad survey on expressive-sensorial characterization of materials for design education. *METU Journal of the Faculty of Architecture, 27*(2), 287-300.
56. Rovers, A. F., & van Essen, H. A. (2005). FootIO – Design and evaluation of a device to enable foot interaction over a computer network. In *Proceedings of the 1st Joint Eurohaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems* (pp. 521-522). Piscataway, NJ: IEEE.
57. Rovers, L., & van Essen, H. A. (2004). Design and evaluation of hapticons for enriched instant messaging. *Virtual Reality, 9*, 177-191.
58. Saito, C. (2015). *(Un)touchable* (Unpublished master's thesis). University of the Arts Bremen, Bremen, Germany.
59. Salter, S. (2014). *Yamamoto & Yohji–The ten greatest yohji-sms*. Retrieved March 29, 2016 from https://i-d.vice.com/en_gb/article/yamamoto-yohji-the-ten-greatest-yohji-sms
60. Savva, N., Scarinzi, A., & Bianchi-Berthouze, N. (2012). Continuous recognition of player's affective body expression as dynamic quality of aesthetic experience. *IEEE Transactions on Computational Intelligence and AI in Games, 4*(3), 199-212.
61. Sennett, R. (2008). *The craftsman.* London, UK: Penguin Books.
62. SHOWstudio, 2006. *The Sound of Clothes*. [online] Available at: <https://showstudio.com/projects/the_sound_of_clothes> [Accessed 13 August 2019].
63. Singh, H., Bauer, M., Chowanski, W., Sui, Y., Atkinson, D., Baurley, S., …Bianchi-Berthouze, N. (2014). The brain's response to pleasant touch: An EEG investigation of tactile caressing. *Frontiers in Human Neuroscience, 8*, 893.
64. Smith, K. (2012). Sensing design and workmanship: The haptic skills of shoppers in eighteenth-century London. *Journal of Design History, 25*(1), 1-10.
65. Sonneveld, M. H., & Schifferstein, H. N. (2008). The tactual experience of objects. In H. Schifferstein & P. Hekkert (Eds.), *Product experience* (pp. 41-67). Amsterdam, the Netherlands: Elsevier.
66. Spence, C., & Gallace, A. (2011). Multisensory design: Reaching out to touch the consumer. *Psychology & Marketing, 28*(3), 267-308.
67. Tallis, R. (2003). *The hand: A philosophical inquiry into human being*. Edinburgh, Scotland: Edinburgh University.
68. Teinaki, V., Montgomery, B., Spencer, N., & Cockton, G. (2012). An aesthetics of touch: Investigating the language of design relating to form. In *Proceedings of the Conference on Design and Semantics of Form and Movement* (pp.170-179). Wellington, New Zealand: Victoria University of Wellington.
69. Valatkiene, L., & Strazdiene, E. (2006). Accuracy and reliability of fabric's hand subjective evaluation. *Materials Science (Medziagotyra), 12*(3), 253-257.
70. Workman, J. E. (2010). Fashion consumer groups, gender, and need for touch. *Clothing and Textiles Research Journal, 28*(2), 126-139.
71. Yu, X. (2016). *Exploring the impact of haptic feedback on the perception of handled fabrics viewing* (Unpublished master's thesis). University College London, London, UK.